VSB TECHNICAL UNIVERSITY OF OSTRAVA
FACULTY OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

Configuration of protection and control relay

Konfigurace ochran a řídících relé

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Master degree diploma thesis

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- Substation description
- Design and function description of substation at VSB
- PCM600 tool description

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- Ito, H. Switching Equipment, Springer 2019
- Krieg, T., Finn, J. Substations, Springer 2019
- IEC 62271-1. High-voltage switchgear and controlgear - Part 1: Common specifications for alternating current switchgear and controlgear. 2017
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- ABB s.r.o.: Technical Manual 620 series. ABB s.r.o. 2019. ID: 1MRS757644

Extent and terms of a thesis are specified in directions for its elaboration that are opened to the public on the web sites of the faculty.

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Abstrakt

V rámci spolupráce mezi VŠB-TUO a evropským provozním centrem ABB v Ostravě byl dokončen projekt návrhu konfigurace řídicího a ochranného relé, který bude použit pro řízení a ochranu laboratorní rozvodny VŠB-TUO.

Tato práce zahrnuje všechny kroky dokončené během realizace projektu. První polovina provádí teoretická data a počáteční data, která jsou nezbytná pro další návrh konfigurace, a druhá část popisuje všechny nástroje, které byly použity k vytvoření konfigurace a hlavních návrhových kroků.

Klíčová slova

Klíčová slova: řízení, dohled, ochrana, IED, relé, CB, odpojovač, blokování, SCADA.

Abstract

Within the cooperation between Technical university of Ostrava and ABB European operation centre of Ostrava there was completed a project of design of control and protection relay configuration which will be used to control and protect the VŠB-TUO substation.

This work includes all the steps completed during realization of the project. The first half performs theoretical data and starting data which are necessary for the further configuration design and the second part describes all the tools which were used to create the configuration and the main design steps.

Keywords

Keywords: control, supervision, protection, IED, relay, CB, disconnector, interlock, SCADA.

Table of content

List of symbols and abbreviations used

AC – Alternating Current,

CT – Current Transformer,

CB – Circuit Breaker,

DC – Direct Current,

GOOSE – Generic Object-Oriented Substation Event,

HV – High Voltage,

HMI – Human Machine Interface,

ICD – IED Capability Description,

IED – Intelligent Electronic Device,

IT – Instrument Transformer,

LED – Light-Emitting Diode,

MV – Medium Voltage,

RTU – Remote Terminal Unit,

SCADA – Supervision, Control and Data Acquisition,

SF6 – Sulfur Hexafluoride,

SLD – Single-Line Diagram,

VŠB-TUO – Vysoká Škola Báňská – Technická Univerzita Ostrava,

VT – Voltage Transformer,

PLC – Programmable Logic Controller.

List of images and charts

1. Introduction

With the increasing dependency of our society on electricity supply, the need to achieve an acceptable level of reliability, quality, and safety at an economic price becomes important to customers. The power system as such is well designed and also adequately maintained to minimize the number of faults that can occur.

The goal of this diploma work is to design control, protection and automation configuration for the model of medium voltage substation which will serve for the purpose of science and will be used for tests of isolation, protection relays and SCADA system.

The diploma work consists of several parts:

- Substation description. The main types of substation, the rules of their design are described in this part,
- Substation at VŠB-TUO. This part includes description of the substation design and its functions,
- PCM600 tool. This part describes the functions and possibilities of this program,
- Configuration of IEDs. This part includes the explanation of function choice, description of IEDs configuration design and description of functional blocks which are used in the configuration,
- IED configuration to control system. This chapter describes the way of IEDs communication to control system and briefly this system itself,
- Conclusion about made work.

2. Substation description

2.1. Substation description

A substation is a part of an electrical system. The main goal of substation is to receive, transform and distribute electrical power. [2]

There are three functions which the transmission and distribution network requires:

1) The transmission of electric power from sources to the load centres,
2) The interconnection functions, which improves security of supply and allows a reduction in generation costs,
3) The supply function, which consists of supplying the electric power to subtransmission or distribution transformers and in some cases to customers directly, connected to the transmission and distribution network.

The following types of substations fulfil these functions:

- Converter substation. These substations serve for converting current type or frequency,
- Substation connected to a power station. The main purpose of this substation is to supply the power system and separate the powerplant from it,
- Interconnection substations. This type of substations serves for collecting energy from power sources and distributing it within the grid,
- Step-up/step-down substations. These substations connect two or more transmission lines. They are arranged to transform transmission voltage to subtransmission voltage or vice versa for the further delivering energy to distribution substation,
- Distribution substation. This type of substation is used to decrease transmission or subtransmission voltage to distribution voltage and further deliver power to final customer. Distribution substations also serve as a voltage control and regulation points.

Each substation may perform more than one of these functions.

Substations can be classified according to the used insulation medium of equipment:

- Air-insulated switchgear (AIS) – insulation to earth and between phases is provided by air at the atmosphere pressure, some live parts are not enclosed,
- Gas-insulated switchgear (GIS) – live parts are metal-enclosed, insulation is obtained by insulating gas (SF6 or an SF6 mixture with other gases),
- Mixed-technology switchgear (MTS) – equipment is developed from AIS or GIS with the following combinations: AIS in compact and/or combined design, GIS in combined design, hybrid insulated switchgear where bays are made from a mis of AIS and GIS technology components.

2.2. The requirements of substation design

Substation design is a really difficult process taking a lot of time. This process begins from carrying out network studies covering insulation coordination, transient stability, short circuit level and load flow. Such kind of research gives parameters which are applied to the whole system.

The parameters which are usually common for the network or part of it:

1. Insulation impulse level – the lightning impulse withstand level and switching withstand impulse level. The IEC standards offer a range of values for each normal operating voltage,
2. Fault clearance time required ensuring system stability. Exceedance of such parameter can lead to asynchronous condition of a system or generators overspeed,
3. Fault current levels – the rating of current impacts the substation equipment,
4. Current rating – the maximum load current passing through the components in the substation,
5. Neutral points earthing – the networks may be solidly or effectively earthed, high or low resistance earthed, resonant earthed or isolated,
6. General control requirement – the methodology of control, the need of telecontrol and telecommunication, load shedding, network sectioning and voltage regulation devices,
7. General protection requirements. All short circuits must be cleared selectively, without exceeding current limits of equipment and causing damage to personnel, as quick as possible and remaining the load/generation balance. Requirements for backup protections should be defined.

Also, there are parameters that are specific for particular substation:

1. General site location,
2. Extent of substation. This depends upon the available area, the number of transformers, breakers, disconnectors, busbars, outgoing feeders and compensating equipment for future possible needs. The lifetime of a substation is between 30 and 50 years,
3. Required availability of the circuits and busbar schemes,
4. Future extensions. It is necessary to estimate the reserve space and extension space. This space depends on the type and functions of substation. Ignorance of this parameter may lead to increase of difficulty and price of reconstruction of existing bays or extensions.

Usually there are several variants of substation location and its configuration, so the cost of building, equipment and reinforcement of existing circuits should be calculated. The following should be considered during the assessing of the overall costs:

1. Site suitability and cost,
2. The losses in power transmission and transformation,
3. Telecontrol and communication,
4. Reliability and busbar scheme,
5. Fault current and load flow calculations.

One more important decision made during substation design is to choose the type of equipment which is going to be installed.

Each substation has approximately the same number of equipment:

- Breakers or switchgears,
- Disconnectors,
- Power transformers,
- Busbars and switchgears,
- Instrument transformers,

- Capacitor banks and reactors,
- Protection equipment.

There are several well-spread types of breakers according to arc-extinguishing area:

1. Oil-isolated breakers. The oil serves as the extinguishing medium and provides the insulation to the tank,
2. Air-blast circuit breakers. The arc is blown into a segmented compartment by the magnetic field generated by the fault current. In this way, the arc length, the arc voltage, and the surface of the arc column are increased. The arc voltage decreases the fault current, and the larger arc column surface improves the cooling of the arc channel,
3. Gas-isolated breakers. SF6 is well suited for application in circuit breakers because it is an electronegative gas, therefore having an affinity for capturing free electrons, which gives rise to the formation of negative ions with reduced mobility. This property leads to rapid removal of electrons present in the plasma of an arc in SF6, thus increasing the arc's conductance decrement rate when the current approaches current zero,
4. Vacuum breakers. The arc in vacuum is maintained by ions of metal material vaporized from the cathode. The density of this metal vapor is proportional with the current, and the plasma reduces when the current approaches zero. At zero value of the current the contact gap is rapidly deionized by condensation of the metal vapor on the electrodes.

There are several factors which must be considered to choose the proper type of a breaker such as installation place, price, operation and service, availability, flexibility, etc. [1] But we can't forget about requirements for choosing a particular circuit breaker:

1. Nominal voltage,
2. Nominal current,
3. Nominal interrupting current,
4. Mechanical withstanding,
5. Thermal withstanding.

Figure 1 – SF6 isolated circuit breaker [10]

The second switching equipment of a substation is disconnector. A disconnector ensures that an electrical circuit is completely deenergized and visually disconnected. There are four types of disconnectors:

1. Centre-break disconnectors,
2. Double-break disconnectors,
3. Pantograph disconnectors,
4. Horizontal knee disconnectors.

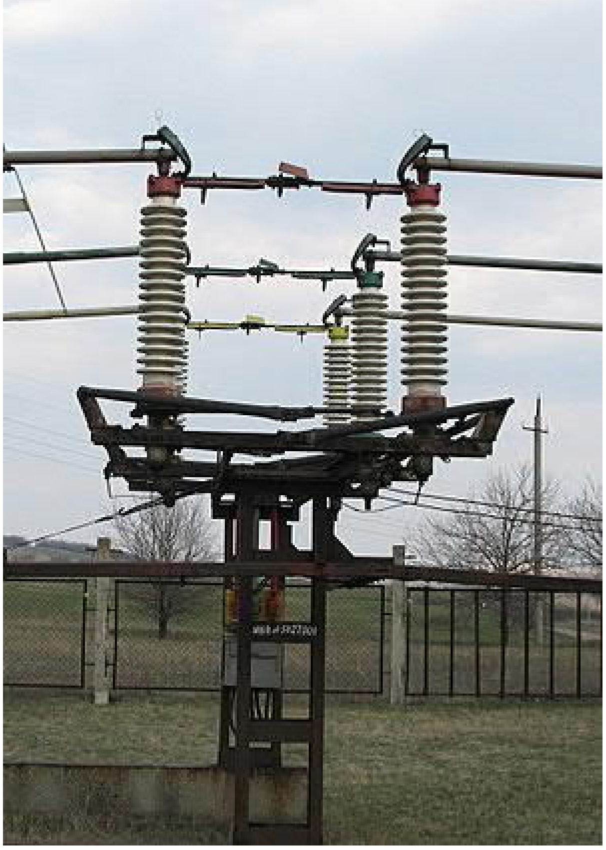

Figure 2 – Horizontal knee disconnector [10]

Disconnectors are selected based upon the sub-station layout, clearances available and space constrains. To choose a particular disconnector the following factors must be considered:

1. Nominal voltage,
2. Nominal current,
3. Mechanical withstanding,
4. Thermal withstanding.

Power transformers are essential components in the AC power system as they make it possible to convert electrical energy to different voltage levels with an efficiency of more than 99%. From the viewpoint of design, power transformers are mainly classified into two different structures: core type and shell type. Isolation medium is usually oil, SF6 or air. The choice of type of a transformer and their number depends on the nominal load, category of consumer, protection and reliability requirements of the system. [2]

Figure 3 – Power transformer [10]

Busbars and switchgears are used to receive and distribute power of a single voltage class. Type of busbar system and its isolation medium (air, SF_6) depends on:

1. The number of incoming and outcoming feeders,
2. The category of consumer,
3. The place of installation,
4. Protection and reliability requirements of the system.

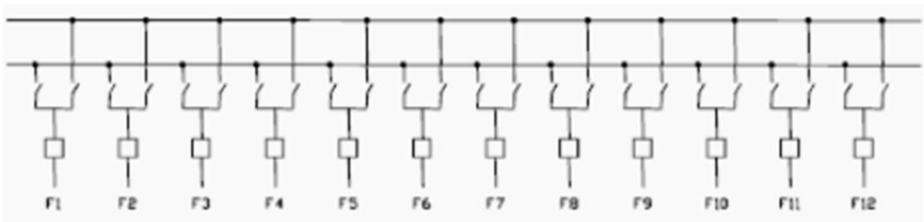

Figure 4 – Double busbar scheme

Instrument transformers are used for measurement of voltage and current in AC circuits. In power systems, levels of currents and voltages are very high that makes direct measurements with conventional instruments impossible without providing operator safety and decreasing size and cost of instruments. There are principally two reasons for use of instrument transformers in measurement:

- to extend (multiply) the range of the measuring instrument,
- to isolate the measuring instrument from a high-voltage line.

The following parameters must be considered to choose an instrument transformer:

1. Nominal voltage,
2. Nominal current,
3. Thermal withstanding,
4. Mechanical withstanding,
5. The necessary accuracy,
6. The resistance of measuring devices.

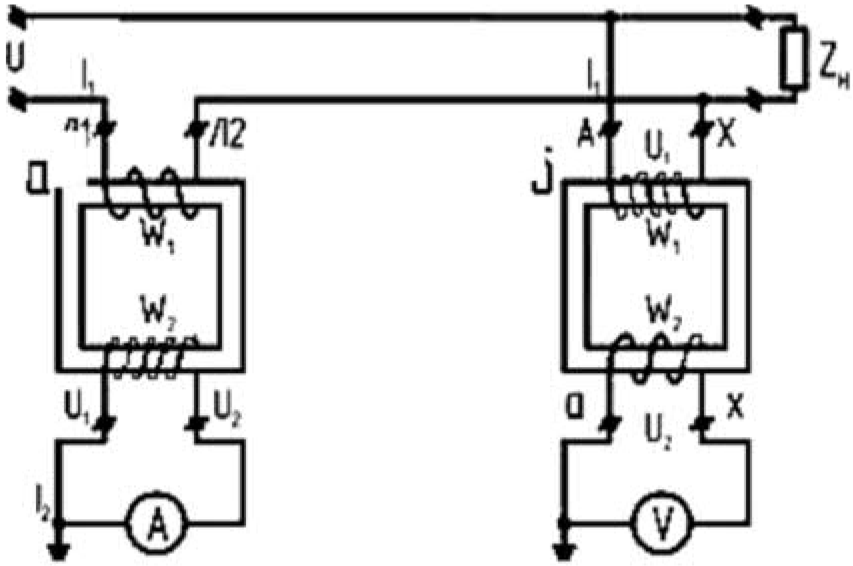

Figure 5 – Schemes of connection of current and voltage transformers

Capacitor banks and reactors are used to compensate some lack or overflow of reactive power respectively. It is necessary to measure the power factor, voltage and current of the system to choose suitable capacitor bank or reactor.

Figure 6 – Capacitor banks [10]

Protection devices are installed to clear faults, like short circuits, because short-circuit currents can damage the cables, lines, busbars, and transformers. The voltage and current measuring transformers provide measured values to the protective relay. The relay processes the data and determines, based on its settings, whether or not it needs to operate a circuit breaker in order to isolate faulted sections or components. Every object must be protected.

Figure 7 – Protection and control device REU615 manufactured by ABB

Every protection must have the following characteristics:

1. Selectivity. Devices must avoid unwarranted, false trips,
2. Reliability. Devices must function consistently when fault conditions occur, regardless of possibly being idle for months or years. Without this reliability, systems may cause costly damages,
3. Speed. Protection must trip as quick as possible to reduce equipment damage and fault and duration,
4. Simplicity (protection must minimize circuity and equipment),
5. Economy (devices must provide maximum protection for minimum price).

There are several basic types of protections:

- Differential protection,
- Overcurrent protection,
- Overvoltage and undervoltage protections,
- Arc-protection,
- Distance protection,
- High-frequency protection.

Also, protections can be classified as main protections and back-up protections. There must be installed two kits of protection devices. Also, back-up protection can be provided with protection of other devices but in this case tripping time and selectivity and reliability may suffer.

All protection devices must be properly set to provide all protection characteristics. It's necessary to know maximum and minimum load, maximum value of short-circuit currents of nodes, the value of nodal voltage in case of abnormal modes and many other parameters to set protection devices properly.

A fuse is an electrical safety device that operates to provide overcurrent protection of an electrical circuit. It combines several basic functions of breakers, current transformers and protection devices. Its essential component is a metal wire or strip that melts when too much current flows through it, thereby disconnecting the circuit and interrupting the short circuit current. A fuse is a weak link in a circuit and as such has one important advantage over circuit breakers. Because the element in the fuse has a much smaller cross section than the cable it protects, the fuse element will reach its melting point before the cable. The larger the current, the quicker the fuse element melts. The fuse interrupts a very large current in a much shorter time than a circuit breaker does, so short in fact that the current will be cut off before it reaches its peak value, which in a 50 Hz system implies operation in less than 5 milliseconds, and serious overheating and electromechanical forces in the system are avoided. This current-limiting action is an important characteristic that has application in many industrial low-voltage installations. The single-shot feature of a fuse requires that a blown fuse has to be replaced before service can be restored. This means a delay, the need to have a spare fuse and qualified maintenance personnel who must go and replace the fuse in the field. In a three-phase circuit, a single-phase-to-ground fault will cause one phase to blow and the other two phases stay connected. When choosing a fuse nominal voltage, maximum short-circuit current and maximum load must be considered.

Figure 8 – Fuses [10]

3. Design and function description of substation at VŠB-TUO

3.1. Function description

The main function of the substation is to serve for the purpose of science and education as a laboratory installation. It was designed to adjust several voltage levels: 6 kV, 22 kV, 35 kV.

Voltage modes on which the substation operates are described below:

- 0 kV mode supposes completely deenergizing of the substations. It allows to maintain the equipment safe and make the necessary preparations in switchgear for further measurements,
- 6 kV mode allows to energize all the equipment. It is possible to use the ZS1 cubicle, on which there can be made some expert measurements, as well as tests for different modes of switchgear operations. This mode also permits both to conduct experiments with the motor and demonstrate the possibilities of the motor protection using REM,
- 22 kV mode serves for performing routine switching operations. All the equipment exceptionally ZS1 cubicle can be energized,
- 35 kV mode provides the possibility to perform HV insulation tests on outputs of HV transformer. The aim of this tests is to study the behavior of different insulation materials which are commonly used in cable manufacturing.

3.2. Designe description

According to the necessary functions, the following single line diagram was created (*figure 11*).

The substation is powered by the 400 V feeder. It consists of the MCB for 400 V and 0-0,4 kV autotransformer. This autotransformer allows to regulate the voltage level of the switchgear via changing its ratio. The AT is connected to the 0,4/35 kV transformer which increases the voltage level. The high voltage side of the transformer is connected to the voltage transformer (BVT1) and to a disconnector (QZ1) with a 35 kV earthing switch (QE). The disconnector is followed by a 24 kV circuit breaker (QB1) and a current transformer (BCT1). BCT1 is connected to the double busbar system by two disconnectors (QZ2 and QZ3).

As a switchgear, the double busbar system is used. This system has the ability to reserve a feeder in comparison with a single busbar system and is flexible enough to change the configuration of the substation as needed. [3] Due to the fact that the main task of the designed switchgear is to use it as a laboratory installation, the visual visibility and simplicity of the double busbar system is an important advantage in choosing the arrangement of the busbars. One of the advantages of a double busbar system is also an opportunity to study the switching of feeder between the two busbar systems, thus it is possible to work out the sequence of actions during routine switching at real substations.

Figure 9 – Control panel of VŠB-TUO substation

However, in conditions of limited space, it can be quite cumbersome, which can complicate the further layout of the main equipment within the substation. Therefore, special attention should be paid to the proper distribution of space within the intended installation site.

The first outgoing connection will consist mainly of two 24 kV disconnectors and a MV circuit breaker designed for 24 kV as well. The second outgoing connection will consist of a ZS1 switchgear (UniGear series from ABB). It is assumed that the switchgear will be equipped with all necessary primary and auxiliary equipment, the voltage level of the switchgear will be 6 kV, the connection to the busbars of the substation will be done through additional 24 kV disconnector, the decision was made for safety purposes, as by direct connection of the switchgear to the busbars, where 24 kV may occur, can cause serious damage to the equipment.

Figure 10 – VŠB-TUO substation

Current measuring is on outputs from both medium voltage circuit breakers. To ensure precise voltage regulation voltage measuring transformers BVT1 are connected on the output from main transformer T1. Voltage monitoring is done by BVT2 and BVT3 on the double busbar system.

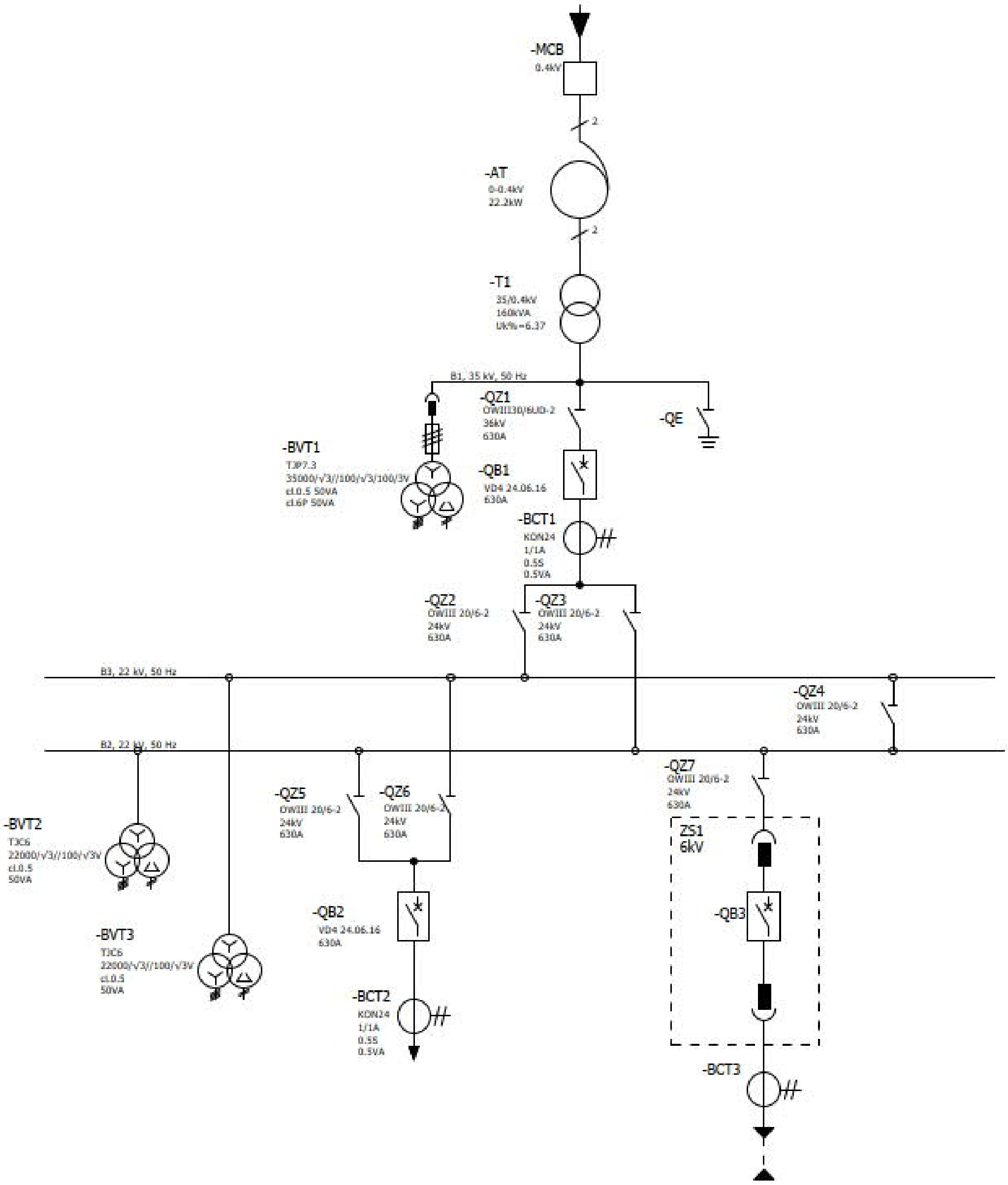

Figure 11 - Single line diagram of designed switchgear

According to the design assignment, the step-up power transformer was chosen. Its parameters are described in Table 1.

Table 1 – Parameters of step-up MV transformer

Parameters	Medium voltage	Low voltage
Rated voltage, kV	35±2×2,5%	0,4
Rated current, A	2,64	231
Rated power, kVA	160	
Winding connection	Dyn-1	
Short-circuit impedance, %	6,37	
Short-circuit losses (P_K), kW	3,335	
No-load losses (P_0), kW	0,48	
Type of cooling	AN	

According to the IEC 62270-100 and the design assignment, the circuit breaker of VD4 series manufactured by ABB, with rated voltage 24 kV, the disconnectors of OW series with rated voltage 24 and 36 kV were accepted for consideration.

In this project, two types of voltage measuring transformers are used, the first type is 35 kV transformers, and the second type is 24 kV transformers. The table below shows the parameters of voltage measuring transformers.

Table 2 – Parameters of the voltage transformers (22 kV)

Primary voltage, V	Secondary voltage		
	Voltage, V	Accuracy	Burden, VA
$22000/\sqrt{3}$	$100/\sqrt{3}$	0,5	50

Since the operating current flowing through the substation busbars has an extremely low value, this directly affects the possible accuracy of current transformers. It was determined that it is not possible to use current transformers from the nominal range for given voltage level, it was decided to order measuring current transformers of a special configuration that would meet all required conditions. The following transformers were designed at the ABB (ELDS) factory in Brno.

Table 3 - Parameters of the designed current transformers

Nominal voltage, kV	Thermal withstanding current (Ith), kA/1s	Dynamical withstanding current (Idyn), kA	Ratio	Accuracy class	Burden, VA
24	0,5	1,3	1/1	0,5S	50

It was chosen to use REU615, RET620 and REF620 to organize proper protection and automation of the substation, what will be discussed in further chapters.

4. PCM600 tool description

The Protection and Control IED Manager PCM600 tool provides versatile functionalities for the entire life cycle of all Relion® protection and control IED applications, at all voltage levels. [6] This tool helps a user to manage a protection and control equipment from application and communication configuration to disturbance handling, including automatic disturbance recording.

PCM600 has the project explorer which allows to navigate the used IED in a project and functionalities of an IED. A plant structure with a substation, voltage levels, bays and IEDs can be created by the user. New IEDs configurations can be started from the scratch or by use of IEDs' templates.

The parameters setting of PCM600 allows to view and set IED parameters offline (stored in the tool) or online (stored in the tool and the device). These parameters can be downloaded from IED to PCM600 or written from PCM600 to IED while IED is in service. Also, the parameters can be exported to XRIO format what allows to conduct test sets or to the CSV format to be easily read and reused.

There are two modes of the parameters setting use:

- The normal mode (allows to look through and change the most used parameters),
- The advanced mode (allows to view all the parameters can be set).

In addition, PCM600 offers to work with all IED parameters or the parameters related to specific function blocks. Also, it is possible to view only parameters that have been changed or parameters which values deviate from the IED's settings.

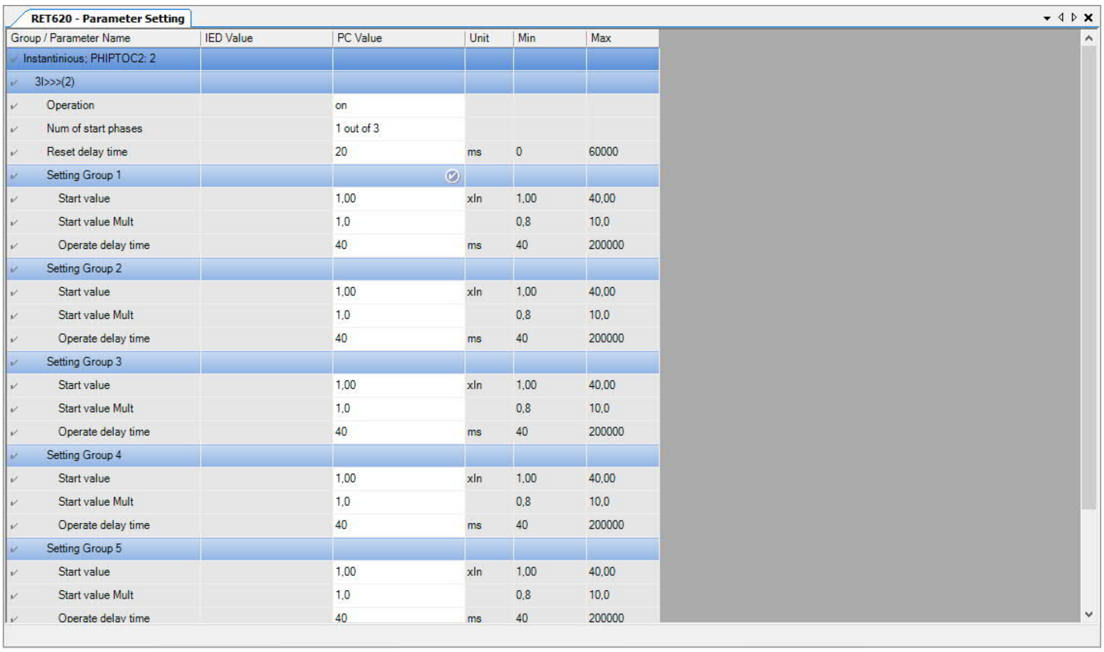

Figure 12 – Parameter setting view

One of the most important options of PCM600 is the graphical application configuration. It allows to create, adapt and modify application configuration. PCM600 also represents routs of signals from inputs to outputs. Before writing the configuration to an IED, the tool offers validation of the complete IED configuration which ensures that the configuration does not contain errors.

Additionally, the user can compare the configuration in the tool to the one in the IED. Further, the signal status on-line monitoring functionality helps to verify the real-time processes in the IED, which is extremely useful for troubleshooting. Also, it is possible to use IED comparison to compare configurations. It can be made offline between the IEDs being in the same project and online when IED is connected to the laptop with the PCM600. The report of comparing is represented as a result of this procedure.

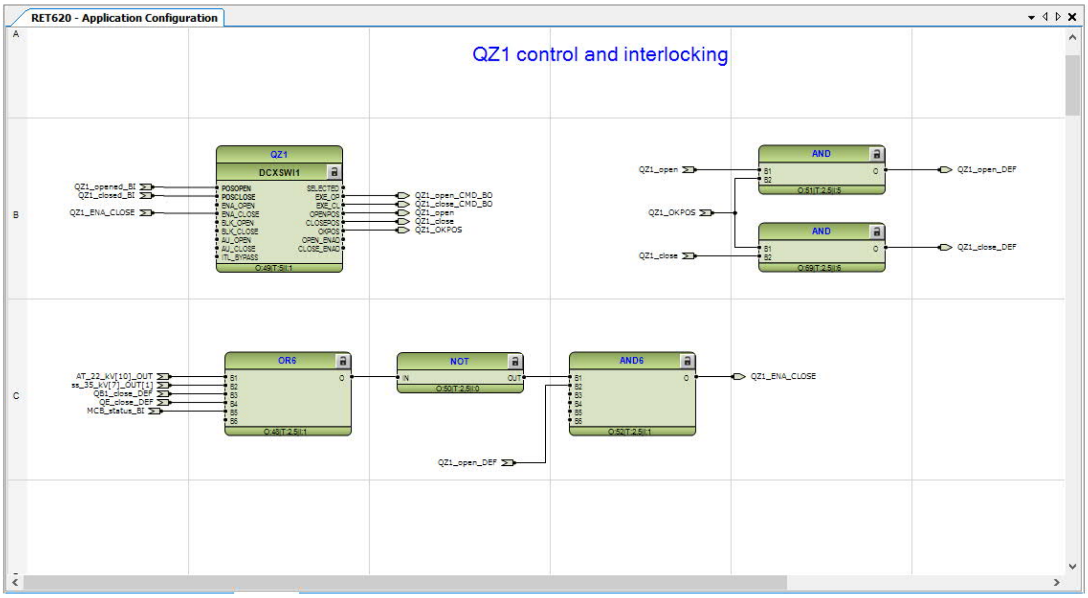

Figure 13 – Application configuration

The graphical signal matrix of PCM600 allows connecting efficiently CTs, VTs, binary input and output signals to the configuration. The configuration can also be changed from here. The tool can also be used for connecting the LEDs on the IED as well as for connection of the GOOSE signals between the IEDs. Once the IEDs have been configured and parameterized, PCM600 enables the configuration of the horizontal bay-to-bay communication for station-wide interlocking and sends the complete IED description to a system engineering tool. [6]

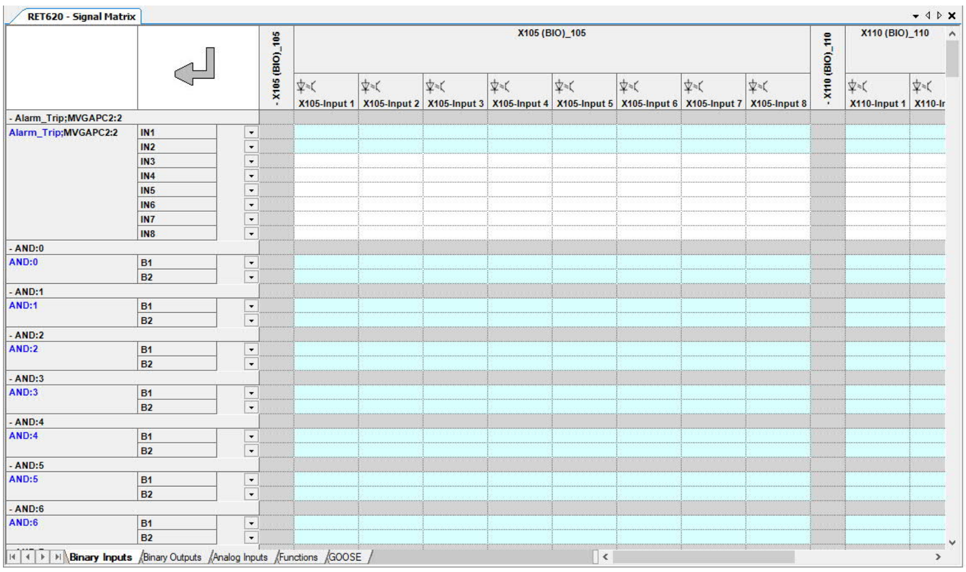

Figure 14 – Graphical signal matrix tool view

Another important PCM600 option is the graphical display editor. It allows to configure the display of an IED. A display consists of one or several pages. Each page contains the drawing area where values of voltage and current or substation configuration can be shown. A display is configured by dragging predefined graphical symbols from a library to the drawing area. The directed link tool can be used to draw connections between symbols. Every symbol type has a corresponding representation in both the ANSI and the IEC symbol palettes. Symbols can be connected to the application configuration.

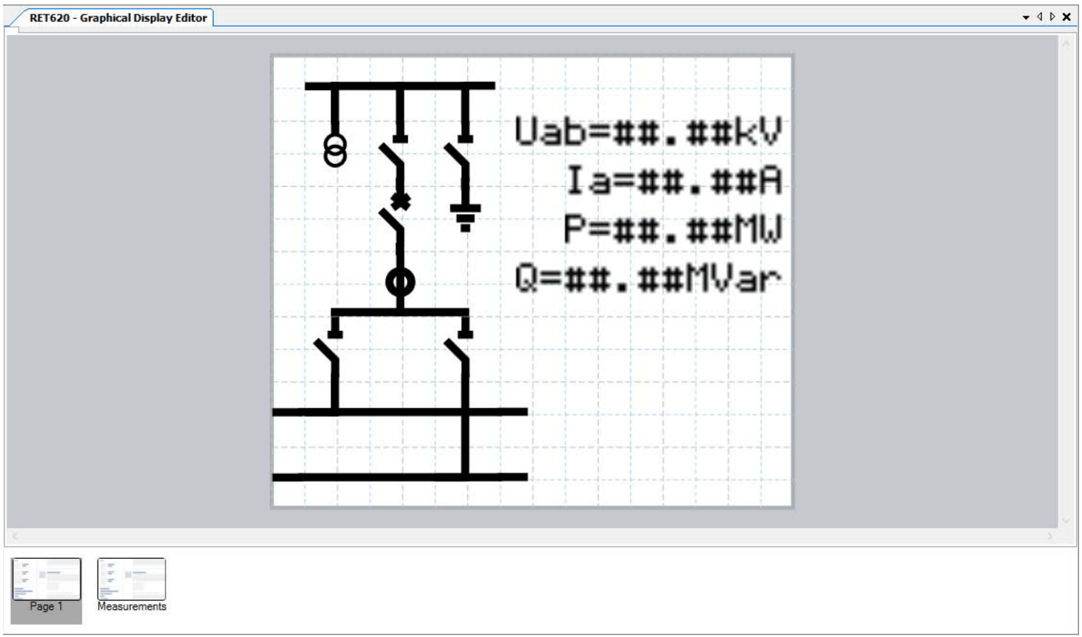

Figure 15 – Graphical display editor

In case of necessity to have a snapshot of all the protections and controlled IEDs of the substation PCM600 can collect all the important data in a browser. This procedure is called IED summering. Its result can be printed for the documents directly from the tool.

The signal monitoring function was designed to provide the user with online information about measured values and status of binary inputs and outputs of IEDs. Furthermore, it is possible to check and test physical connections via the signal monitoring tool.

Also, PCM600 allows to view the security events, monitor disturbance records from the IED. The disturbance files are saved in COMTRADE format and allow the user to view it in any disturbance analyzer. The report can be adapted to user-specific needs. In addition, PCM600 can be set to read records, make a report and send it to the subscribers automatically to shorten the time from disturbance detection to correct actions.

In case of necessity to provide vertical and horizontal communication, the user can use the ICE 61850 configuration tool of PCM600. It allows to view and configure IEC618520 datasets, different communication protocols like DNP3, IEC 60870-5-101/103/104 or Modbus.

To sum it up, the conclusion can be made that PCM600 tool provides all the necessary functions to create protection of a substation.

5. Selection of control and protection functions in PCM600

It is said in the chapter 3 that the REU615, RET620 and REF620 had been chosen to provide automation and protection functions for the substation. But it is necessary to choose the proper functions for the current project.

The list of the chosen functions is below:

- Measuring function,
- Voltage control,
- Circuit breakers and disconnectors control and supervision,
- Protection functions,
- Disturbance recording,
- Communication.

5.1. Measuring function

It is necessary to know the value of currents, voltages, etc. to provide proper protection and operation of power system.

Each IED receives the signals from different ITs. RET620 and REU615 are connected to voltage transformer BVT1 and current transformer BCT1. REF620 is connected to a couple of voltage transformers BVT2 and BVT3 and the current transformer BCT2.

It was decided to measure the following values:

- Phase currents and voltages,
- Sequence currents and voltages,
- Residual currents and voltages,
- Three-phase power and energy,
- Frequency and power factor.

5.2. Voltage control function

The VŠB-TUO substation is designed to work under different levels of voltage (see chapter 3). That is why it is necessary to organize proper voltage control and possibility of its regulation without any danger for a human.

The autotransformer is used for this purpose. The signal of its micro switches and the position of the selector switch are sent to the IED. The main goal of the IED is to provide the interlocks which will be discussed in the following chapter.

5.3. Circuit breakers and disconnectors control and supervision

There are two CBs, seven disconnectors and one earthing switch. Each of these devices need to be controlled and supervised both locally and remotely. The IEDs receive the signals of the equipment statuses and send the open/close commands to a CB or disconnector. Also, the IEDs are set to provide the necessary interlocks which are described in the chapter 6.

CBs and disconnectors control and supervision functions are widely used in real substations. They allow to decrease the probability of operator's mistakes and diminish the harm of equipment faults such as CB fault.

5.4. Protection function

Protection function is highly important. The main goal of it is to detect and separate damaged elements from the power system in case of short circuits or other abnormal work modes to decrease their harm impact.

It was decided to use three-step overcurrent, overvoltage and undervoltage protections.

Overcurrent protection is the most spread kind of protections among power systems. The protection operates when the value of current becomes higher than the set level.

Overvoltage protection prevents overvoltage conditions because they can cause the aging of isolation and creation of dangerous potentials at the low voltage equipment. It operates when the value of voltage becomes higher than the set level.

Undervoltage protection is used to prevent the voltage drop below the operation value because it can lead to heavy losses for different kinds of manufacturing and to damage of other electrical equipment. It operates when the value of voltage gets below the set level.

Direct overcurrent protection is not effective in the case of VŠB-TUO substation because the current can flow only in one direction. The zero-sequence protections cannot be used too because the circuit is isolated and zero-sequence currents will not exist in case of short circuit. Differential and residual current protections cannot be used because of the absence of the necessary number of CT. Distance protection is used to protect power lines.

Protection function representation in PCM600 will be described in the chapter 6.

5.5. Disturbance recording function

Sometimes there can happen abnormal regimes such as short circuits, overloads, equipment faults and many others. It is necessary to analyze them to improve protection system, diminish possibility of their repeat and decrease their impact for the system in the future.

The disturbance recorder is used for post-fault analysis and for verifying the correct operation of protection relays and circuit breakers. [4] It allows to record both analog and binary signals and store them.

There are usually used values of phase currents and voltages, the values of sequence currents and sequence voltages, the values of active, reactive and apparent power, the statuses of CBs and disconnectors and operators acts.

5.6. Communication function

The standards of each country require proper monitoring and control of technical process. That is why the communication function is so important.

The IEDs need to send the data not only to one another but also to control system. They send the magnitudes of measured values, CBs and disconnectors positions and many others.

Each technical process requires its own communication system. The communication system of this project is described in the chapters 6 and 7.

6. Configuration of IEDs according to function description

There were described the necessary functions for the IEDs in the previous chapter. Some of them are common for the IEDs but several ones are special for a specific relay. This chapter describes the configuration of IEDs according to their functions and function blocks which are used in this configuration.

6.1. Configuration description

The configuration of each IED consists of several pages. Every page is in charge of its own function.

6.1.1. Measuring function

Measuring function is common for all the relays. Each one is connected to instrument transformers and receives the necessary measures. IEDs receive only voltage and current of every phase but using this data they can calculate the sequence values of voltage and current, active and reactive power, etc. All the data is automatically sent to disturbance recorder and to protection function blocks in Relion 615 and 620 series.

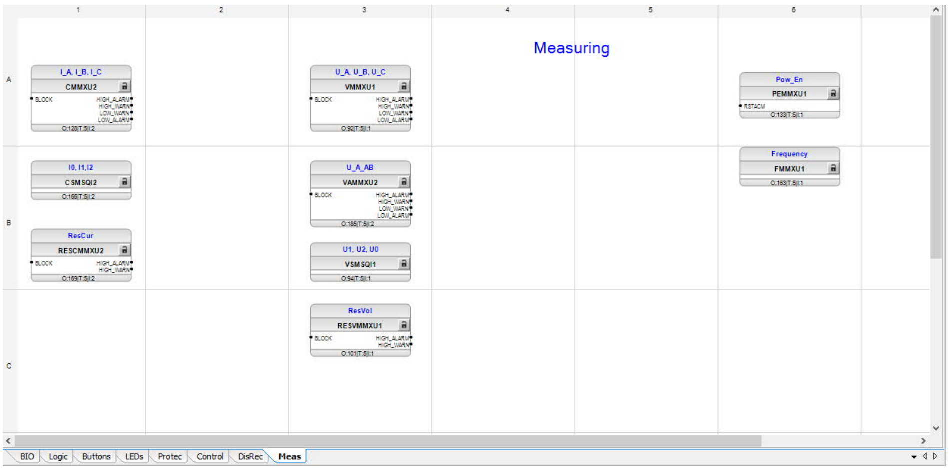

Figure 16 – Configuration of the measuring page of the RET620

6.1.2. Voltage control function

REU615 was chosen to provide voltage regulation and control function. Increasing and decreasing of voltage are accomplished by pushing the control panel pushbuttons. The signal is sent from the panel to REU615. REU615 has specially designed blocking which does not allow to increase voltage under the following interlocks:

- The selector switch is set up in position 0 kV,
- The selector switch is set up in position 6 kV and the micro switch position 6 kV is activated,
- The selector switch is set up in position 22 kV and the micro switch position 22 kV is activated or disconnector QZ7 is closed,
- The selector switch is set up in position 35 kV and the micro switch position 35 kV is activated or disconnector QZ7 or disconnector QZ1 are closed.

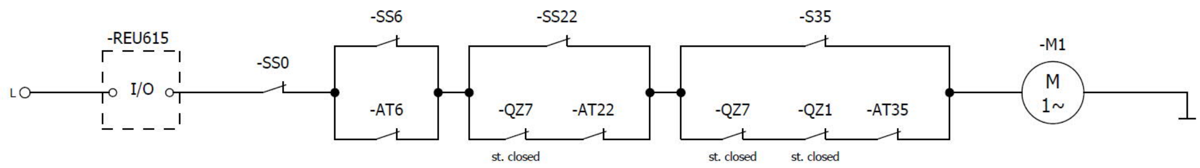

Figure 17 – Interlock for voltage raising

Interlocks for voltage diminishing are not used.

6.1.3. Circut breakers and disconnectors control and supervision function

Circuit breakers and disconnectors control and supervision function is important. It was decided that REF620 and RET620 provided this function. RET620 controls circuit breaker QB1, disconnectors QZ1, QZ2 and QZ3 and earthing switch QE. REF620 is responsible for disconnectors QZ4, QZ5, QZ6 and QZ7 and circuit breaker QB2. The IEDs receive data about statuses of circuit breakers and disconnectors and allow them to operate remotely. There were designed interlocks for breakers and disconnectors operation. Opening does not require any interlocks. The Individual interlocks for each CB and disconnector can be found below.

Disconnector QZ1 closing is forbidden when:

- The selector switch is set up in position 35 kV,
- Micro switch position 22 kV is active (NC contact will open),
- Medium voltage circuit breaker *QB1* is closed,
- Earthing switch *QE* is closed,
- Disconnector *QZ1* is not in the fully opened position.

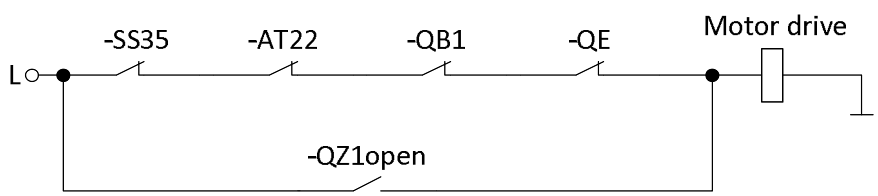

Figure 18 – Interlock for disconnector QZ1

Earthing switch QE closing is forbidden when:

- Circuit braker MCB is closed,
- Circuit breaker QB1 is closed,
- Earthing switch QE is not in the fully opened position.

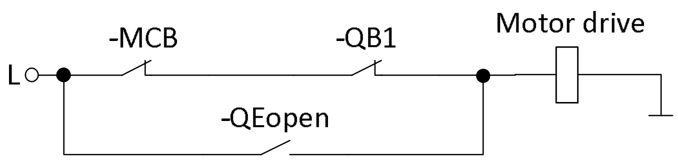

Figure 19 – Interlock for earthing switch QE

Disconnector QZ2 closing is forbidden when:

- The selector switch is set up in position 6 kV,

- Disconnector QZ3 is closed,
- Disconnector QZ2 is not in the fully opened position.

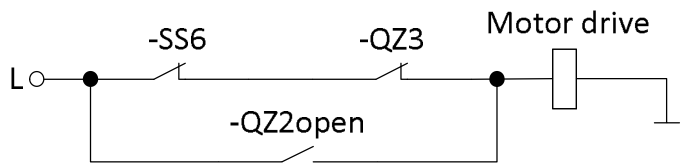

Figure 20 – Interlock for disconnector QZ2

Disconnector QZ3 closing is forbidden when:

- Disconnector QZ2 is closed,
- Disconnector QZ3 is not in the fully open position.

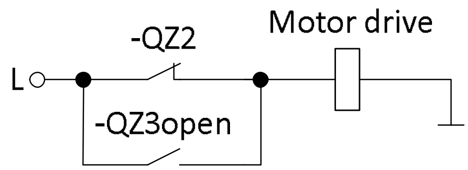

Figure 21 – Interlock for disconnector QZ3

Disconnector QZ4 closing is forbidden when:

- The selector switch is set up in position 6 kV,
- Disconnector QZ4 is not in the fully open position.

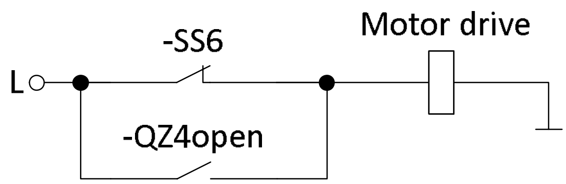

Figure 22 – Interlock for disconnector QZ4

Disconnector QZ5 closing is forbidden when:

- Disconnector QZ6 is closed,
- Disconnector QZ5 is not in the fully open position.

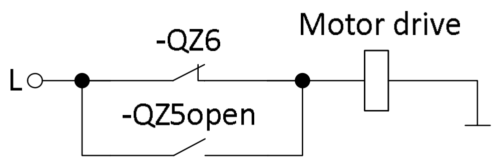

Figure 23 – Interlock for disconnector QZ5

Disconnector QZ6 closing is forbidden when:

- Disconnector QZ5 is closed,
- Disconnector QZ6 is not in the fully open position.

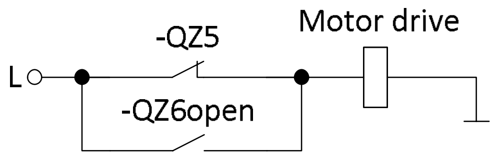

Figure 24 – Interlock for disconnector QZ6

Disconnector QZ7 closing is forbidden when:

- The selector switch is set up in position 22 kV,
- The selector switch is set up in position 35 kV,
- Micro switch position 6 kV is active (NC contact will open),
- Disconnector QZ7 is not in fully open position.

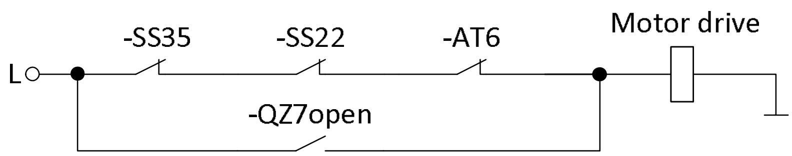

Figure 25 – Interlock for disconnector QZ7

Circuit breaker QB1 closing is forbidden when:

- Earthing switch QE is closed,
- Disconnector QZ1 is open,
- The selector switch is set up in position 35 kV,
- Micro switch position 22 kV is active (NC contact will close),
- Spring charge is not ready.

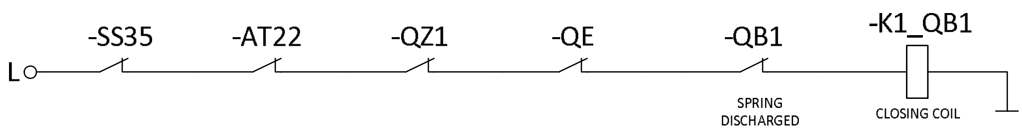

Figure 26 – Interlock for circuit breaker QB1

Circuit breaker QB2 closing is forbidden when:

- Earthing switch QE is closed,
- Disconnectors QZ5 or QZ6 are opened,
- The selector switch is set up in position 35 kV,
- Micro switch position 22 kV is active (NC contact will open),
- Spring charge is not ready.

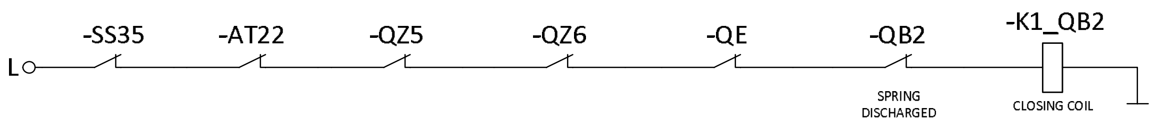

Figure 27 – Interlock for circuit breaker QB2

It can be seen that there were used fully open position status. The IEDs allow to get these signals artificially using "OK_POS", "Open" and "Close" status signals. "OK_POS" signal has logical "1" on the output when disconnector or CB are in fully open or fully close position. So, the signals, that we need, can be get with using basic logic functions.

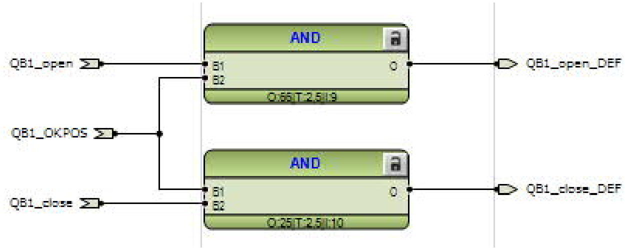

Figure 28 – Receiving fully open and fully close status

6.1.4. Protection functions

Sometimes abnormal regimes such as short circuits, overloads and many other faults can happen in the power network. They can cause damage to equipment, economical loses and harm to people or even lead to death. So, it is really important to suppress these regimes to avoid their consequences.

As it has been said in the chapter 5, it was decided to use overcurrent, overvoltage and undervoltage protections to keep equipment and people safe.

There are three steps of overcurrent protection: instantaneous, high and low. Instantaneous and high stages have independent tripping curve and low stage has dependent one.

The substation was created to work with three voltage levels, so it is necessary to set three setting groups. The IEDs allow to set them. There is special function block which gives an option change the setting group with changing the selector switch position.

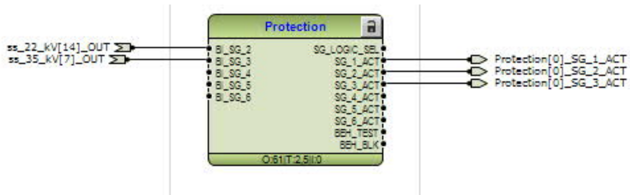

Figure 29 – Block for setting group changing

Each protection block sends two signals: start signal, which is sent to tripping logic, and alarm signal, which is sent to the LEDs. It is possible to reset tripping logic and alarm signal with pressing corresponding programmable pushbuttons.

Besides described protections above, CB fault protection is used. In case of CB fault this protection sends the signal to the undervoltage coil to CB and alarm signal to a LED.

Communication between IEDs is also protected. Each signal has its quality bits and in case of communication problems alarm signal is sent to a LED.

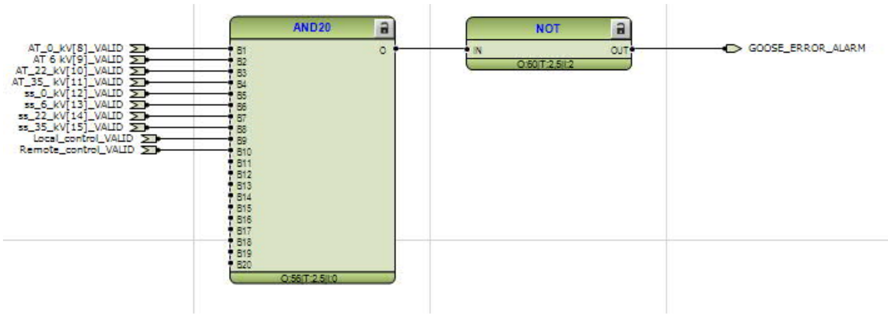

Figure 30 – Configuration of GOOSE error protection

Also, the internal fault protection (IRF) is installed in each relay. Its settings are default and can't be changed. The IRF contact functions as an output contact for the self-supervision system of the protection IED. Under normal operating conditions, the IED is energized and the contact is closed (X100:3-5). When a fault is detected by the self-supervision system or the auxiliary voltage is disconnected, the output contact drops off and the contact closes (X100:3-4). [5]

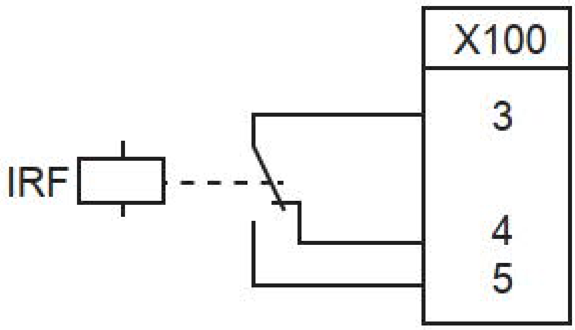

Figure 31 – Internal fault signal output [5]

6.1.5. Disturbance recording

Each IED is required to have disturbance recording function. It allows to record analog and binary data. This data is important for analysis of different situations in power system. For instance, it allows to optimize relay settings and workers action during fault to minimize its impact on the equipment and producing process.

The following values and statuses were decided to record:

- The values of phase currents and voltages,
- The selector switch position,
- AT micro switch position,
- Each protection status,
- CBs and disconnectors positions,
- Chosen setting group number.

This data can help to improve configuration of relays in case of any faults.

6.1.6. Local/remote control

This function allows to control the IED locally or remotely. There are several modes of local/remote control. It can be changed manually by pushing the pushbutton on the relay or automatically by receiving the necessary signals.

6.1.7. Communication

All three IED are connected to the ethernet switch and to the control system to exchange the necessary data. GOOSE protocol is used for data exchange among IEDs such as:

- The selector switch position (from REU615 to RET620 and REF620),
- AT micro switch position (from REU615 to RET620 and REF620),
- Local/remote control status (from REU615 to RET620 and REF620),
- Disconnector QZ1 position (from RET620 to REU615),
- Earthing switch QE position (from RET620 to REF620),
- Disconnector QZ7 position (from REF620 to REU615).

The communication between IEDs and control system will be thoroughly described in the following chapter.

6.2. Functional blocks desription

The configuration created in PCM600 consists of different functional blocks. They represent multiple functions of IEDs. Each block has its own characteristics, a number of inputs and outputs and enable settings. The function blocks which were used for this configuration are described in following chapters.

6.2.1. Binary input and binary output function blocks

These function blocks represent the binary signals on the inputs and outputs of IEDs' terminals. They can have only logical "I" or "0" as a value.

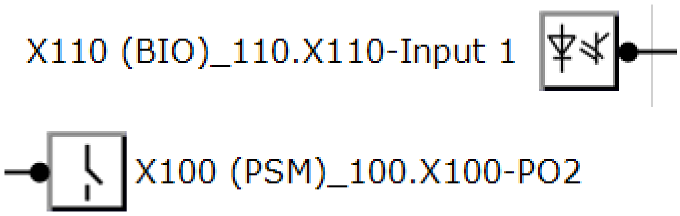

Figure 32 – Binary input and output function block [5]

It is possible to set filter time and input inversion for each input.

6.2.2. GOOSERCV_BIN function bock

The GOOSERCV_BIN function is used to connect the GOOSE binary inputs to the application.

Figure 33 – GOOSERCV_BIN function block [5]

The “VALID” output indicates the validity of received GOOSE data, which means in case of valid, that the GOOSE communication is working and received data quality bits (if configured) indicate good process data. Invalid status is caused either by bad data quality bits or GOOSE communication failure.

The “OUT” output passes the received GOOSE value for the application. Default value (0) is used if VALID output indicates invalid status.

6.2.3. MVGAPC function block

The function MVGAPC is used for user logic bits. Each input state is directly copied to the output state. This allows the creating of events from advanced logic combinations. [5]

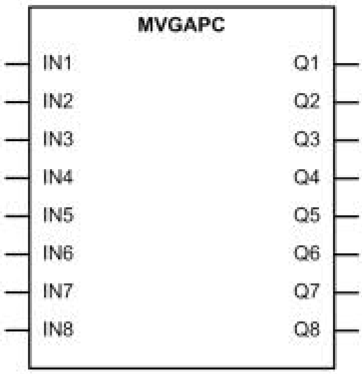

Figure 34 – MVGAPC function block [5]

This block is used to send the signals among IEDs and to control system.

6.2.4. Control function block

Control function block allows to choose between local and remote control via binary signals.

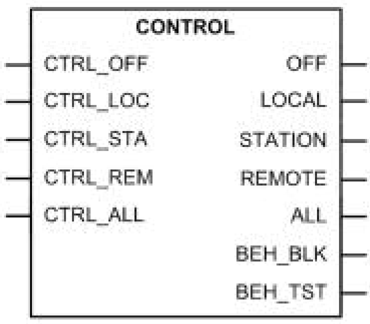

Figure 35 – Control function block [5]

Local/Remote control is by default operated through the R/L button on the front panel. The control via binary input can be enabled by setting the value of the LR control setting to "Binary input". The binary input control requires that the CONTROL function is instantiated in the product configuration. [5]

The actual Local/Remote control state is evaluated by the priority scheme on the function block inputs. If more than one input is active, the input with the highest priority is selected. The actual state is reflected on the CONTROL function outputs. Only one output is active at a time.

Table 4 – Truth table for Control

Input				Output
CTRL_OFF	CTRL_LOC	CTRL_STA	CTRL_REM	
TRUE	ANY	ANY	ANY	OFF=TRUE
FALSE	TRUE	ANY	ANY	LOCAL=TRUE
FALSE	FALSE	TRUE	ANY	STATION=TRUE
FALSE	FALSE	FALSE	TRUE	REMOTE=TRUE
FALSE	FALSE	FALSE	FALSE	OFF=TRUE

If station authority is not in use, the “CTRL_STA” input is interpreted as “CTRL_REM”.

The station authority check can be enabled by setting the value of the Station authority setting to "Station, Remote" (The command originator validation is performed only if the LR control setting is set to "Binary input"). The station authority check is not in use by default.

It is possible to choose the following station authority modes:

- L, R,
- L, R, L+R,
- L, S, R,
- L, S, S+R, L+S, L+S+R.

6.2.5. Programmable buttons function block FKEYGGIO

The programmable buttons function FKEYGGIO is a simple interface between the panel and the application. The user input from the buttons available on the front panel is transferred to the assigned functionality and the corresponding LED is “ON” or “OFF” for indication. The behavior of each function key in the specific application is configured by connection with other application functions. This gives the maximum flexibility.

Inputs “L1” up to “L16” represent the LEDs on the protection relay's LHMI. When an input is set to TRUE, the corresponding LED is lit. When a function key on LHMI is pressed, the corresponding output “K1” up to “K16” is set to “TRUE”.

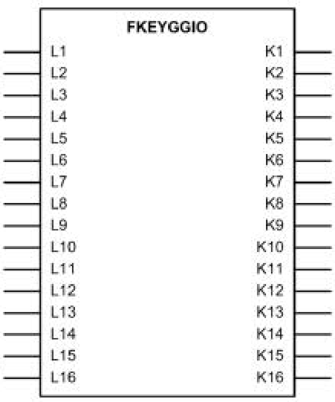

Figure 36 – Function block FKEYGGIO [5]

6.2.6. Function block SPCGAPC

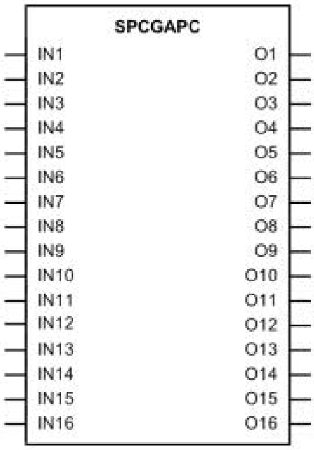

Figure 37 – Function block SPCGAPC [5]

The generic control point (16 pcs) function SPCGAPC is used in combination with other function blocks such as FKEYGGIO. SPCGAPC offers the capability to activate its outputs through a local or remote control. The local control is provided through the buttons in the front panel and the remote control is provided through communications. SPCGAPC has two modes of operation. In the "Toggle" mode, the block toggles the output signal for every input pulse received. In the "Pulsed" mode, the block generates an output pulse of a preset duration.

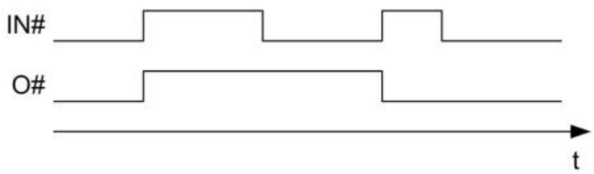

Figure 38 – Operation in "Toggle" mode [5]

6.2.7. LEDs function block

Each LED is seen in the Application Configuration tool as an individual function block. Each LED has user-editable description text for event description. The state ("None", "OK", "Alarm") of each LED can also be read under a common monitored data view for programmable LEDs.

The LED status also provides a means for resetting the individual LED via communication. The LED can also be reset from configuration with the "RESET" input.

The resetting and clearing function for all LEDs is under the Clear menu.

Each LED has two control inputs, "ALARM" and "OK". The color setting is common for all the LEDs. It is controlled with the Alarm colour setting, the default value being "Red". The "OK" input corresponds to the color that is available, with the default value being "Green".

Changing the Alarm colour setting to "Green" changes the color behavior of the "OK" inputs to red.

The "ALARM" input has a higher priority than the "OK" input.

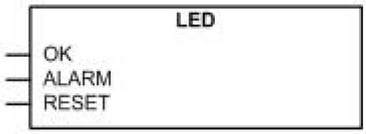

Figure 39 – LED function block [5]

The “ALARM” input behavior can be selected with the alarm mode settings from the alternatives:

- "Follow-S". In this mode “ALARM” follows the input signal value, Non-latched,
- "Follow-F". Similar to "Follow-S", but instead the LED is flashing when the input is active, Non-latched,
- "Latched-S". This mode is a latched function. At the activation of the input signal, the alarm shows a steady light. After acknowledgement by the local operator pressing any key on the keypad, the alarm disappears,
- "LatchedAck-F-S". This mode is a latched function. At the activation of the input signal, the alarm starts flashing. After acknowledgement, the alarm disappears if the signal is not present and gives a steady light if the signal is present.

The “OK” input behavior is always according to "Follow-S".

6.2.8. Protection function blocks

There are used the following function blocks, according to the necessary protection functions:

- PHIPTOC (three-phase non-directional overcurrent protection, instantaneous stage),
- PHHPTOC (three-phase non-directional overcurrent protection, high stage),
- PHLPTOC (three-phase non-directional overcurrent protection, low stage),
- PHPTOV (three-phase overvoltage protection),
- PHPTUV (three-phase undervoltage protection),
- CCBRBRF (CB failure protection).

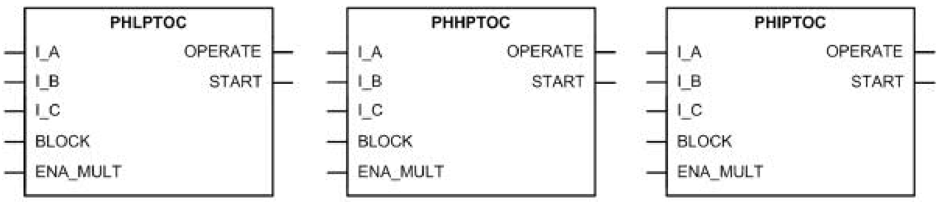

Figure 40 – Three-phase non-directional overcurrent protection function blocks [5]

The three-phase non-directional overcurrent protection function has three steps: instantaneous, high and low stages. The function starts when the current exceeds the set limit. The operate time characteristics for low stage PHLPTOC and high stage PHHPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The instantaneous stage PHIPTOC always operates with the DT characteristic. In the DT mode, the function operates after a predefined operate time and resets when the fault current is not present anymore. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

Also, it is possible to set the minimum number of start phases required to start the timer and send the signal to a CB.

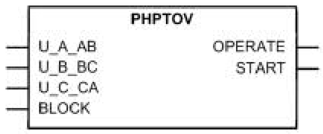

Figure 41 – Three-phase overvoltage protection function block [5]

The three-phase overvoltage protection function PHPTOV is applied on power system elements, such as generators, transformers, motors and power lines, to protect the system from excessive voltages that could damage the insulation and cause insulation breakdown. The three-phase overvoltage function includes a settable value for the detection of overvoltage either in a single phase, two phases or three phases.

PHPTOV includes both DT and IDMT characteristics for the delay of the trip.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

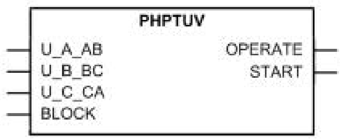

Figure 42 – Three-phase undervoltage protection function block [5]

The three-phase undervoltage protection function PHPTUV is used to disconnect from the network devices, for example electric motors, which are damaged when subjected to service under low voltage conditions. PHPTUV includes a settable value for the detection of undervoltage either in a single phase, two phases or three phases.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

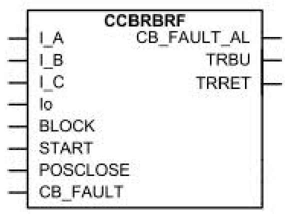

Figure 43 – CB failure protection function block [5]

The circuit breaker failure protection function CCBRBRF is activated by trip commands from the protection functions. The commands are either internal commands to the terminal or external commands through binary inputs. The start command is always a default for three-phase operation. CCBRBRF includes a three-phase conditional or unconditional re-trip function, and also a three-phase conditional back-up trip function.

CCBRBRF uses the same levels of current detection for both re-trip and back-up trip. The operating values of the current measuring elements can be set within a predefined setting range. The function has two independent timers for trip purposes: a re-trip timer for the repeated tripping of its own breaker and a back-up timer for the trip logic operation for upstream breakers. A minimum trip pulse length can be set independently for the trip output.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

6.2.9. Setting group selection function block

The protection relay supports six setting groups. Each setting group contains parameters categorized as group settings inside application functions.

The active setting group can be changed by a parameter or via binary inputs depending on the mode selected with the "Configuration/Setting Group/SG" operation mode setting.

The default value of all inputs is "FALSE", which makes it possible to use only the required number of inputs and leave the rest disconnected.

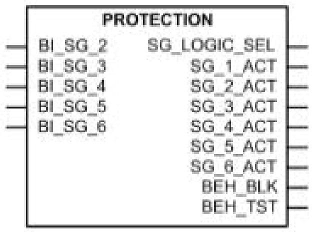

Figure 44 – Setting group selection function block [5]

6.2.10. Circuit breaker, disconnector and earthing switch contol function blocks

CBXCBR, DCXSWI and ESXSWI are intended for circuit breaker, disconnector and earthing switch control and status information purposes. These functions execute commands and evaluate block conditions and different time supervision conditions. The functions perform an execution command only if all conditions indicate that a switch operation is allowed. If erroneous conditions occur, the functions indicate an appropriate cause value.

The circuit breaker, disconnector and earthing switch control functions have an operation counter for closing and opening cycles. The counter value can be read and written remotely from the place of operation or via LHMI.

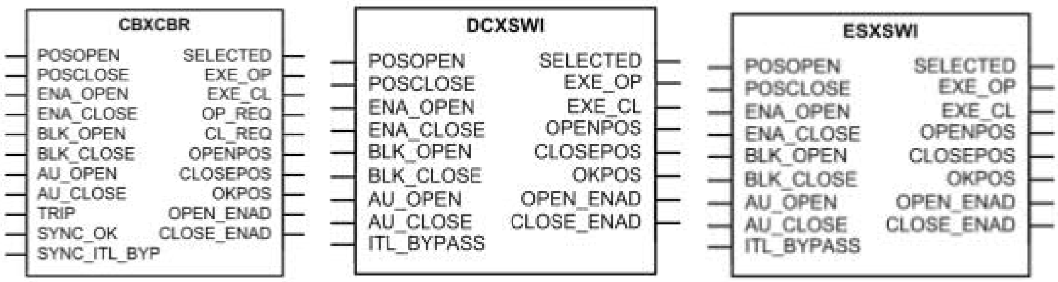

Figure 45 – Circuit breaker, disconnector and earthing switch control function blocks [5]

The object state is defined by two digital inputs, “POSOPEN” and “POSCLOSE”, which are also available as outputs “OPENPOS” and “CLOSEPOS” together with the “OKPOS”. The debouncing and short disturbances in an input are eliminated by filtering. The binary input filtering time can be adjusted separately for each digital input used by the function block. The validity of the digital inputs that indicate the object state is used as additional information in indications and event logging. The reporting of faulty or intermediate position of the apparatus occurs after the Event delay setting, assuming that the circuit breaker is still in a corresponding state.

CBXCBR, DCXSWI and ESXSWI have an enabling and blocking functionality for interlocking.

6.2.11. Disturbance recorder function block

The relay is provided with a disturbance recorder featuring up to 12 analog and 64 binary signal channels. The analog channels can be set to record either the waveform or the trend of the currents and voltages measured.

The analog channels can be set to trigger the recording function when the measured value falls below or exceeds the set values. The binary signal channels can be set to start a recording either on the rising or the falling edge of the binary signal or on both.

By default, the binary channels are set to record external or internal relay signals, for example, the start or trip signals of the relay stages, or external blocking or control signals. Binary relay signals, such as protection start and trip signals, or an external relay control signal via a binary input, can be set to trigger the recording. Recorded information is stored in a non-volatile memory and can be uploaded for subsequent fault analysis.

The user can map any analog signal type of the protection relay to each analog channel of the disturbance recorder by setting the Channel selection parameter of the corresponding analog channel. In addition, the user can enable or disable each analog channel of the disturbance recorder by setting the Operation parameter of the corresponding analog channel to "on" or "off".

All analog channels of the disturbance recorder that are enabled and have a valid signal type mapped are included in the recording.

The user can define the length of a recording with the Record length parameter. The length is given as the number of fundamental cycles.

The sampling frequency of the disturbance recorder analog channels depends on the set rated frequency. One fundamental cycle always contains the amount of samples set with the “Storage rate” parameter. Since the states of the binary channels are sampled once per task execution of the disturbance recorder, the sampling frequency of binary channels is 400 Hz at the rated frequency of 50 Hz and 480 Hz at the rated frequency of 60 Hz.

Disturbance recorder has two operation modes: saturation and overwrite mode. The user can change the operation mode of the disturbance recorder with the “Operation mode” parameter.

In saturation mode, the captured recordings cannot be overwritten with new recordings. Capturing the data is stopped when the recording memory is full, that is, when the maximum number of recordings is reached. In this case, the event is sent via the state change (“TRUE”) of the

“Memory full” parameter. When there is memory available again, another event is generated via the state change (“FALSE”) of the “Memory full” parameter.

When the operation mode is "Overwrite" and the recording memory is full, the oldest recording is overwritten with the pre-trigger data collected for the next recording. Each time a recording is overwritten, the event is generated via the state change of the “Overwrite of rec.” parameter. The overwrite mode is recommended, if it is more important to have the latest recordings in the memory. The saturation mode is preferred, when the oldest recordings are more important.

6.2.12. Measuring function blocks

There were used the following function blocks:

- CMMXU (the tree-phase current measurement function),
- CSMSQI (the sequence current measurement function),
- RESCMMXU (the residual current measurement function),
- VMMXU (the three-phase voltage measurement function),
- VAMMXU (the single-phase voltage measurement function),
- VSMSQI (the sequence voltage measurement function),
- RESVMMXU (the residual voltage measurement function),
- PEMMXU (the three-phase power and energy measurements function),
- FMMXU (the frequency measurement function).

Each function block allows to set the number of samples per period, measurement units and measuring mode.

There are four measuring modes:

- RMS,
- DFT,
- Peak-to-peak,
- Peak-to-peak with peak backup.

RMS consists of both AC and DC components. The AC component is the effective mean value of the positive and negative peak values. RMS is used in applications where the effect of the DC component must be taken into account.

RMS is calculated according to the following formular:

$$I_{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} I_i^2}, \qquad (Equation\ 1)$$

where n – the number of samples,

I_i – the current sample value.

In the DFT mode, the fundamental frequency component of the measured signal is numerically calculated from the samples. In some applications, for example, it can be difficult to accomplish sufficiently sensitive settings and accurate operation of the low stage, which may be due to a considerable amount of harmonics on the primary side currents. In such a case, the operation can be based solely on the fundamental frequency component of the current. In addition, the DFT mode has slightly higher CT requirements than the peak-to-peak mode, if used with high and instantaneous stages.

“Peak-to-peak” is the fastest measurement mode, in which the measurement quantity is made by calculating the average from the positive and negative peak values. The DC component is not included. [5]

“Peak-to-peak with peak backup” is similar to the peak-to-peak mode, with the exception that it has been enhanced with the peak backup. In the peak-to-peak with peak backup mode, the function starts with two conditions: the peak-to-peak value is above the set start current or the peak value is above two times the set Start value. The peak backup is enabled only when the function is used in the DT mode in high and instantaneous stages for faster operation.

7. IED communication to control system

IEDs receive a lot of information from the system. But it is necessary to summarize all of the data at one place to provide proper supervise and control. That is why SCADA system is used.

SCADA is a control system architecture comprising computers, networked data communications and graphical user interfaces (GUI) for high-level process supervisory management, while also comprising other peripheral devices like PLC and PID controllers to interface with process plant or machinery. The use of SCADA has been considered also for management and operations of project-driven-process in construction.

SCADA systems are used for:

- thorough technical process conducting, stabilization of product quality and decreasing the possibility of rejects,
- shifting the operator's attention to creating more effective control of technical process,
- program control of remote commands which leads to minimization of operator's mistakes,
- automatic determination and alarm of fault situations,
- creation of the reports containing all the necessary information for personnel,
- analysis of the forces which have impact on the product quality.

SCADA systems have following benefits:

- reliability,
- safe control,
- accuracy of processing and providing of information,
- simplicity of system expansion.

SCADA has five levels:

- Level 0 contains the field devices such as flow and temperature sensors, and final control elements, such as control valves.
- Level 1 contains the industrialized input/output (I/O) modules, and their associated distributed electronic processors.
- Level 2 contains the supervisory computers, which collate information from processor nodes on the system, and provide the operator control screens.
- Level 3 is the production control level, which does not directly control the process, but is concerned with monitoring production and targets.
- Level 4 is the production scheduling level.

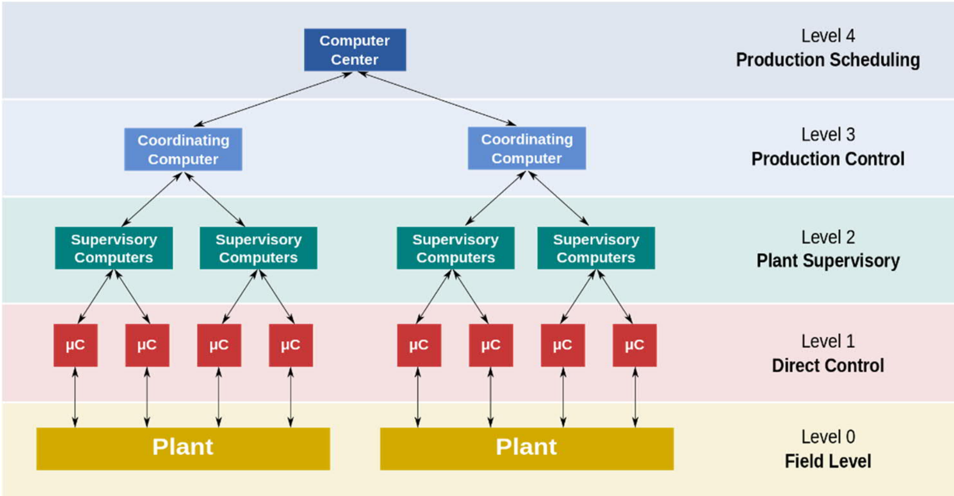

Figure 46 - Functional levels of a manufacturing control operation [9]

SCADA usually consists of the following elements:

- Supervisory computers. This is the core of the SCADA system, gathering data on the process and sending control commands to the field connected devices,
- RTUs and PLCs. They connect to sensors and actuators in the process and are networked to the supervisory computer system,
- Communication infrastructure. It connects the supervisory computer system to the RTUs and PLCs and may use industry standard or manufacturer proprietary protocols,
- HMI. It presents plant information to the operating personnel graphically in the form of mimic diagrams, which are a schematic representation of the plant being controlled, and alarm and event logging pages. The HMI is linked to the SCADA supervisory computer to provide live data to drive the mimic diagrams, alarm displays and trending graphs.

IEDs represent the first level of SCADA system. They receive and process large amount of data from different sensors, transformers and other devices. It is necessary to organize and send the necessary information to the control system. There was created the special signal list for this purpose. It includes all the signals which need to be sent to the control system, their description, datasets, report control blocks, type of signals and the devices which send the signal.

#	Signal Description			RET620	REU615	REF620	Dataset	Report Control Block
1	BREAKER 1			X	-	-		
2	Breaker Position Indication	CTRL.CBCSWI1.Pos (ST)	ST	x	-	-	B	A
3	Breaker Open Select Command	CTRL.CBCSWI1.Pos.ctlSelOff	CO	x	-	-	B	n/a
4	Breaker Close Select Command	CTRL.CBCSWI1.Pos.ctlSelOn	CO	x	-	-	B	n/a
5	Breaker Open Execute Command	CTRL.CBCSWI1.Pos.ctlOperOff	CO	x	-	-	B	n/a
6	Breaker Close Execute Command	CTRL.CBCSWI1.Pos.ctlOperOn	CO	x	-	-	B	n/a
7	Breaker Close Enable	CTRL.CBCILO1.EnaCls (ST)	ST	x	-	-	B	A
8	BREAKER 2			-	-	X		
9	Breaker Position Indication	CTRL.CBCSWI1.Pos (ST)	ST	-	-	x	B	A
10	Breaker Open Select Command	CTRL.CBCSWI1.Pos.ctlSelOff	CO	-	-	x	B	n/a
11	Breaker Close Select Command	CTRL.CBCSWI1.Pos.ctlSelOn	CO	-	-	x	B	n/a
12	Breaker Open Execute Command	CTRL.CBCSWI1.Pos.ctlOperOff	CO	-	-	x	B	n/a
13	Breaker Close Execute Command	CTRL.CBCSWI1.Pos.ctlOperOn	CO	-	-	x	B	n/a
14	Breaker Close Enable	CTRL.CBCILO1.EnaCls (ST)	ST	-	-	x	B	A

Figure 47 – Part of the signal list

According to the signal list described above, all the IEDs are set. Data sets were configured. Each of them is responsible for their own type of signals. The following signals, which are sent to the control system, are listed below:

- CBs, disconnectors and earthing switch statuses,
- CBs, disconnectors and earthing switch selection and operation commands,

- CBs, disconnectors and earthing switch enabling statuses,
- Protection operate and alarm signals,
- Tripping logic trip signals,
- CBs springs statuses,
- Voltage transformers MCBs statuses,
- Door position status,
- Autotransformer micro switch position,
- The selector switch position,
- Supply circuit status,
- Voltage up and down commands,
- Undervoltage coil statuses,
- The values of phase currents and voltages, power factor, frequency, active, reactive and apparent power, active and reactive energy.

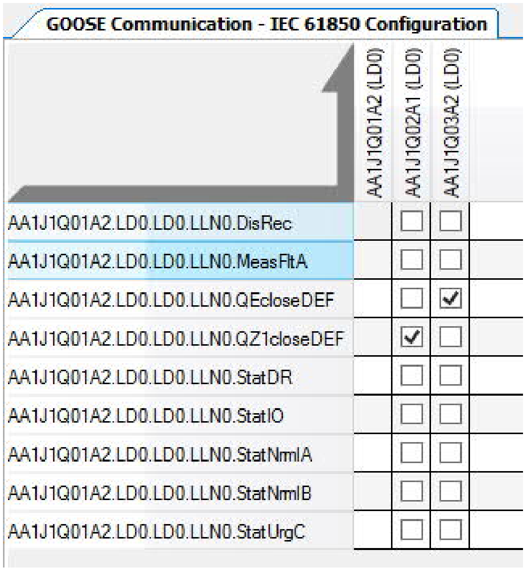

Figure 48 – Datasets configured for RET620

8. Conclusion

In the process of performing this thesis, a number of important results were obtained.

The first step includes description of the main classification of substations focused on substation functions and isolation medium. Also, the main requirements of substation design were listed and the main equipment was enumerated.

The goal of the second step was to analyze the functions of the VŠB-TUO substation, its configuration and the main equipment.

The first two steps were conducted to provide the necessary information for choosing the functions which will be used in the IEDs. As a result of this part voltage regulation, control and supervision, disturbance recording, communication and reasonable protection function were chosen. Also, the media served for IEDs programming was shortly described.

The results of the fourth step are design of the interlocks which are necessary to provide control and supervision, and the realization of them. Also, the chosen earlier functions were configured in PCM600.

As a result of the fifth part, the communication among the IEDs and control system was designed. The SCADA system benefits were considered. The signal list was compiled, and the data sets were created according to it.

The final step includes uploading the configuration to the IEDs, fixing several mistakes and setting the relays for their further work for VŠB-TUO substation.

Thus, this work reflects all the steps of IEDs configuration creation. But it is worth considering that there is no information about 6 kV load of the substation. So, the configuration of the IEDs can be changed if it would be required.

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